

APS Beam Stabilization and Photon Diagnostics Status and Plans

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Beam Stabilization

- **Beam Stability Specification**
- **System overview**
- **Accomplishments to date**
- **Improvement plans**

Beam Stability Specification

1) Original engineering specification 5% of CDR beam size values

- **4.5 microns rms vertical (@ ID source points)**
- **17 microns horizontal**

2) With present low-emittance lattice, (1% coupling) this amounts to

- **590 nm rms vertical**
- **12.6 microns horizontal**

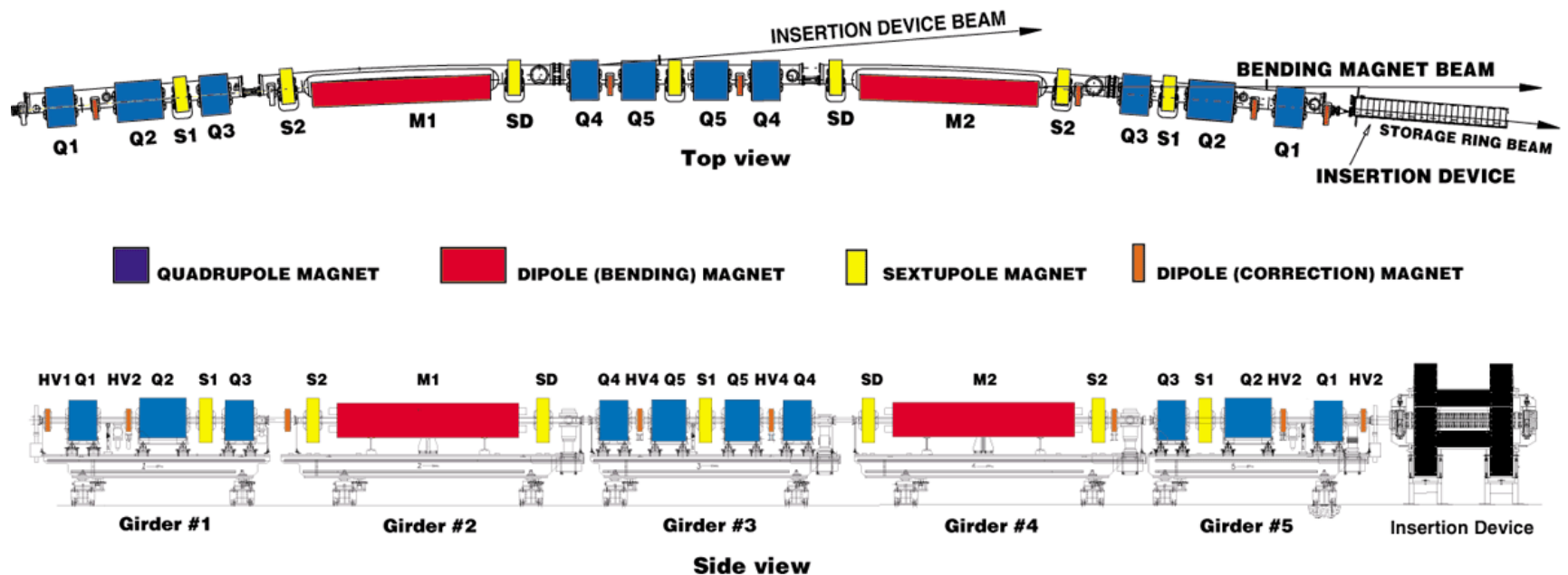
APS Orbit Correction System Components

- **360 broadband (monopulse) RF BPMs**
- **48 narrowband RF BPMs (mounted on ID vacuum chambers)**
- **48 insertion device X-ray BPMs**
- **38 bending magnet X-ray BPMs**
- **317 combined-function horizontal / vertical corrector magnets**

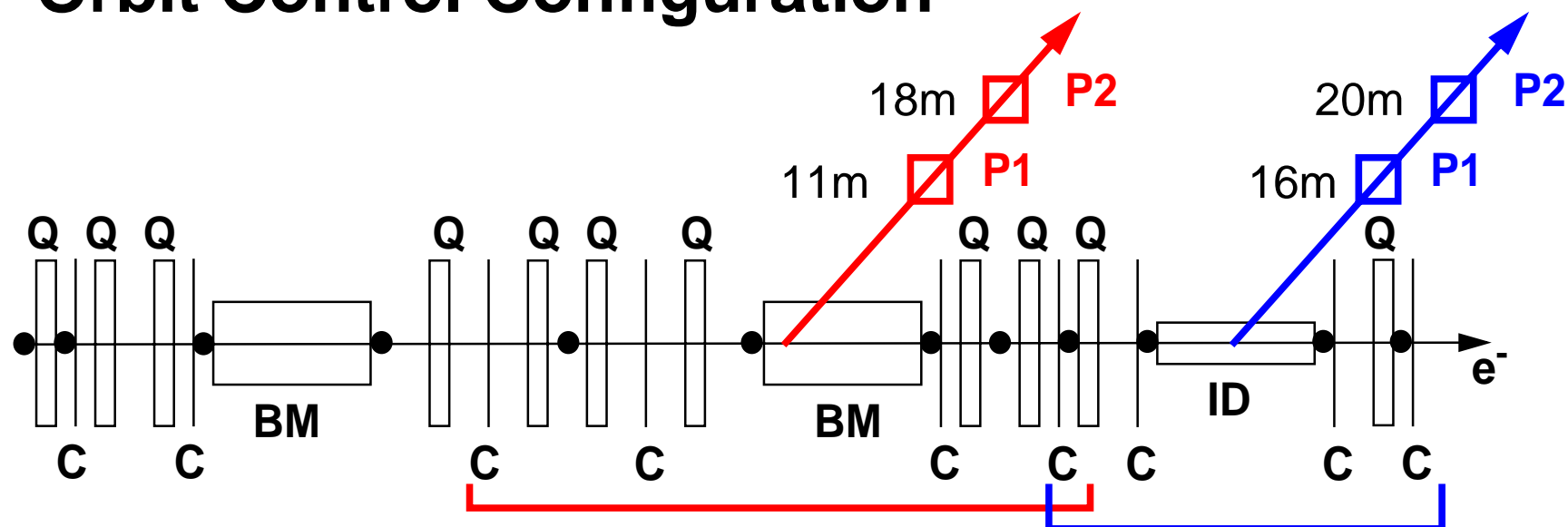
APS Orbit Correction System Components (cont'd)

- **21 VME crates, each with 2 DSP boards for real-time feedback**
- **One additional DSP board used in feedback crates for X-ray and narrowband BPM data acquisition and filtering.**
- **Singular Value Decomposition (SVD) algorithm used in DC and AC systems.**
- **Workstation-based (DC) algorithm has 0.1 Hz closed loop BW**
- **Real-time (AC) algorithm operates from 0.1 to 60 Hz**
 - **Access to 38 “fast” correctors**
 - **Access to all RF and X-BPM data (not all used in algorithm)**

One Sector of the Advanced Photon Source Storage Ring



Orbit Control Configuration



Legend:

C: Corrector Magnet

●: RF Beam Position Monitor

X: X-ray Beam Position Monitor

Q: Quadrupole

BM: Bending Magnet

ID: Insertion Device

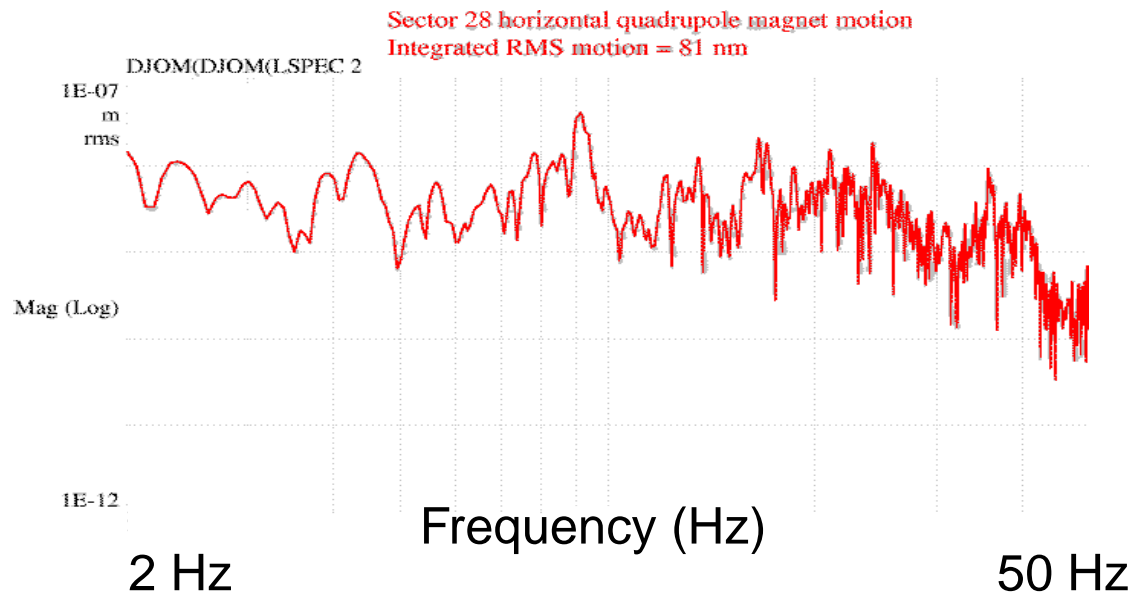
Config.	BPMs	Correctors
Global	11 RF (all)	2
Local - 1	P1 or P2	4
Local - 2	P1 and P2	4

Noise Sources Impacting APS Orbit Stability

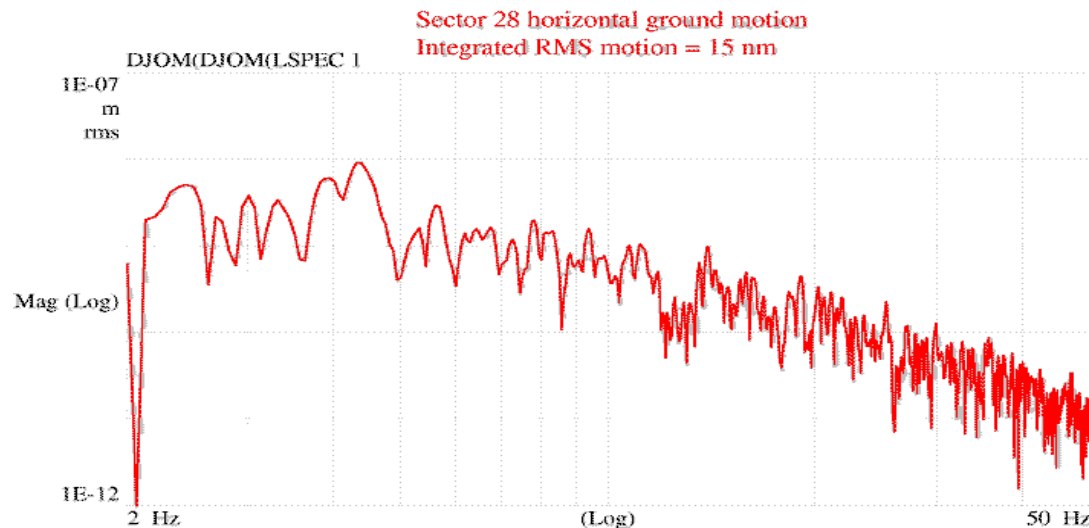
- **Magnet power supply noise / ripple**
 - Dominant source of beam motion
 - Control power upgrade 20% complete
 - DSP-based regulator prototyped
- **RF system high voltage power supply**
 - Induces 360 Hz phase (energy) ripple + harmonics
- **Thermal effects (Tunnel air / water temperature)**
- **Earth tides**
- **Insertion device gap changes**
- **Mechanical vibration**
 - Affects primarily horizontal beam motion

Spectrum of Ground and Magnet Motion, 2 - 50 Hz

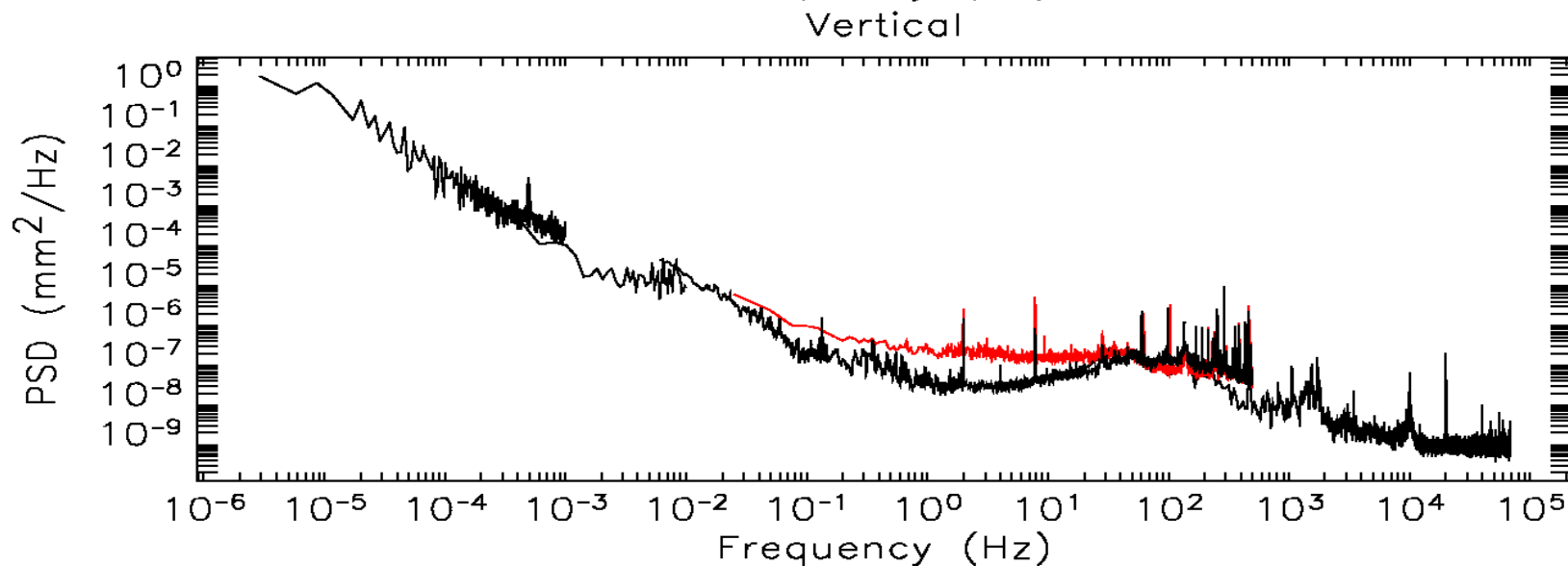
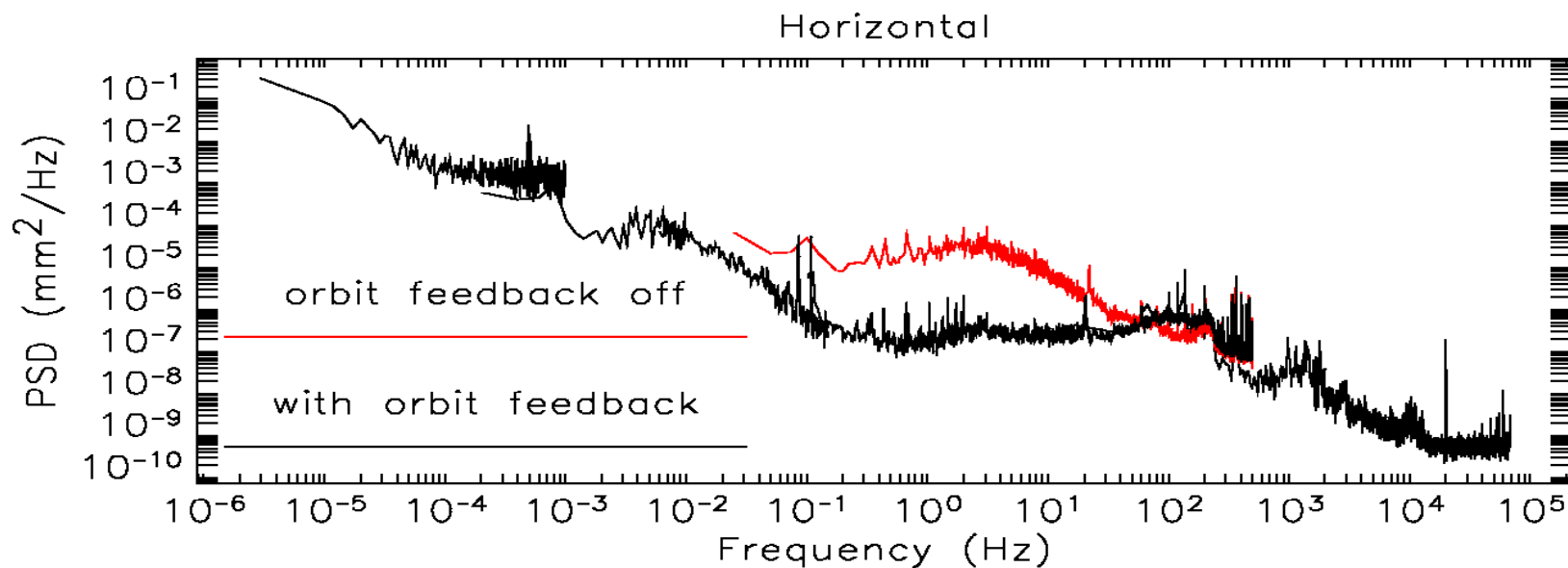
Horizontal
Quadrupole
Displacement
Spectrum

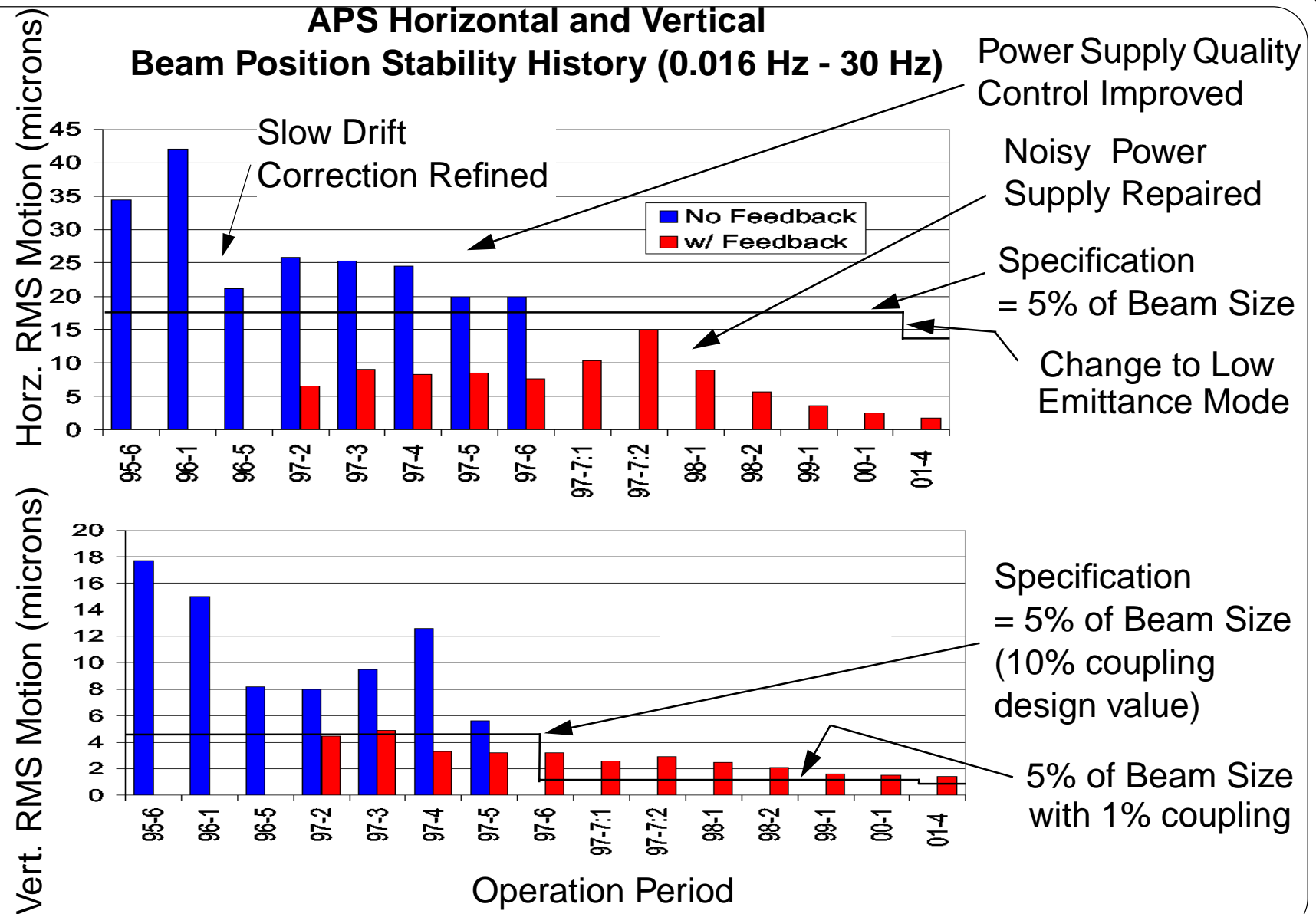


Horizontal
Ground
Motion
Spectrum

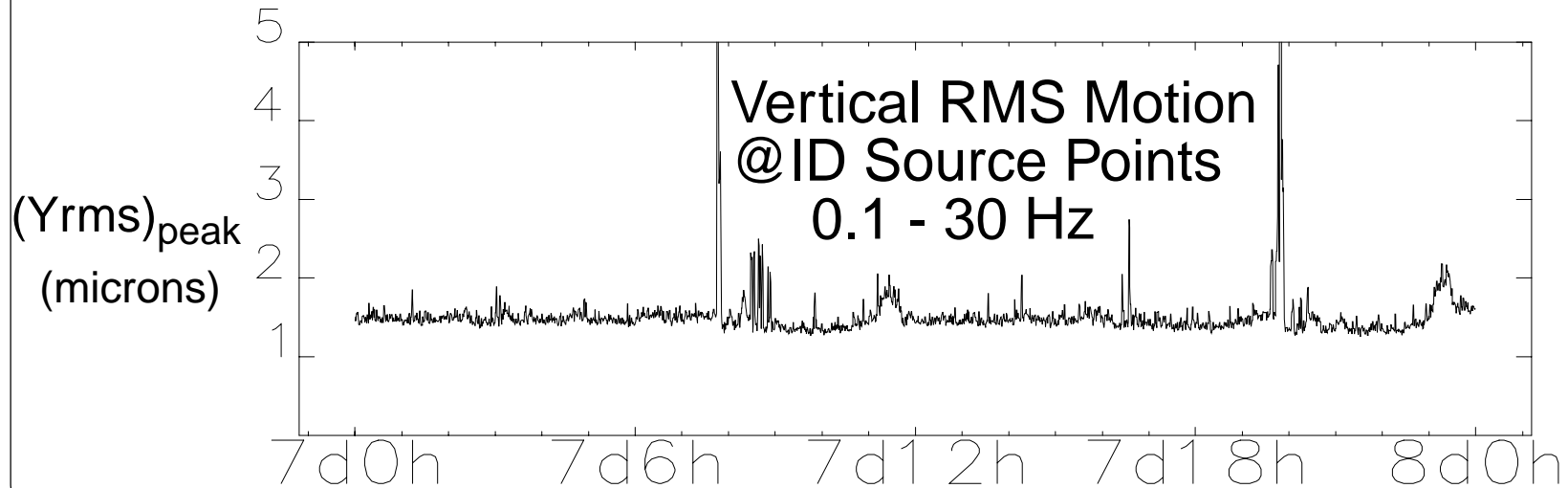
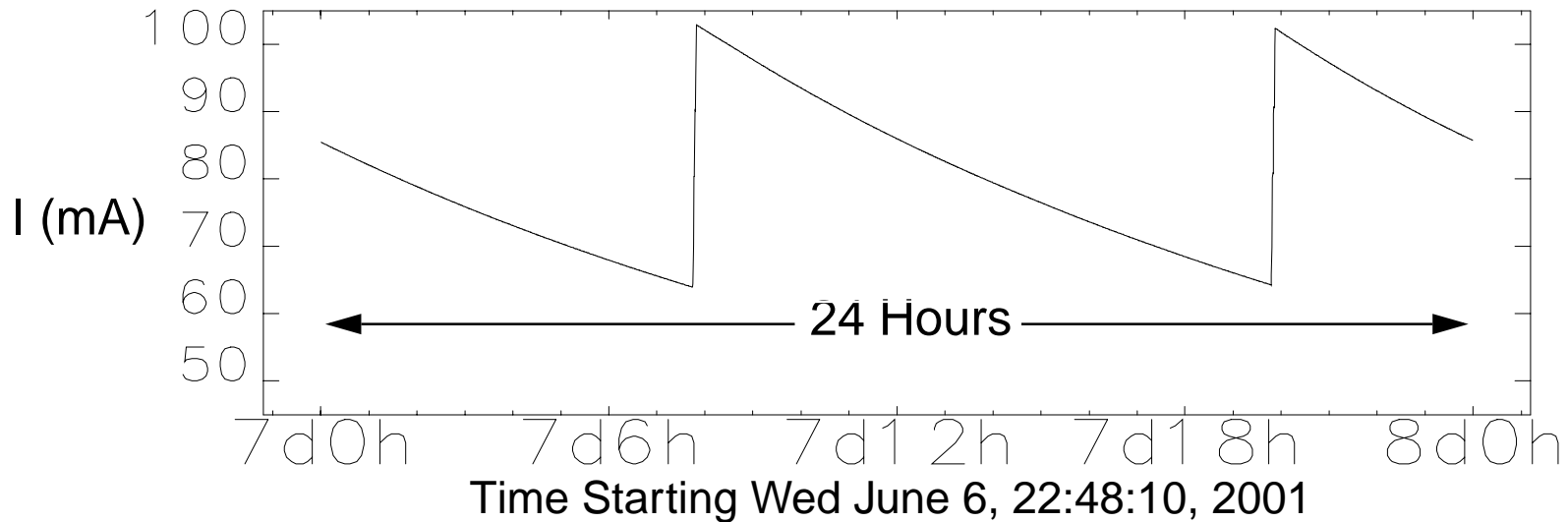


Spectrum of Beam Motion Averaged over ID Source Points

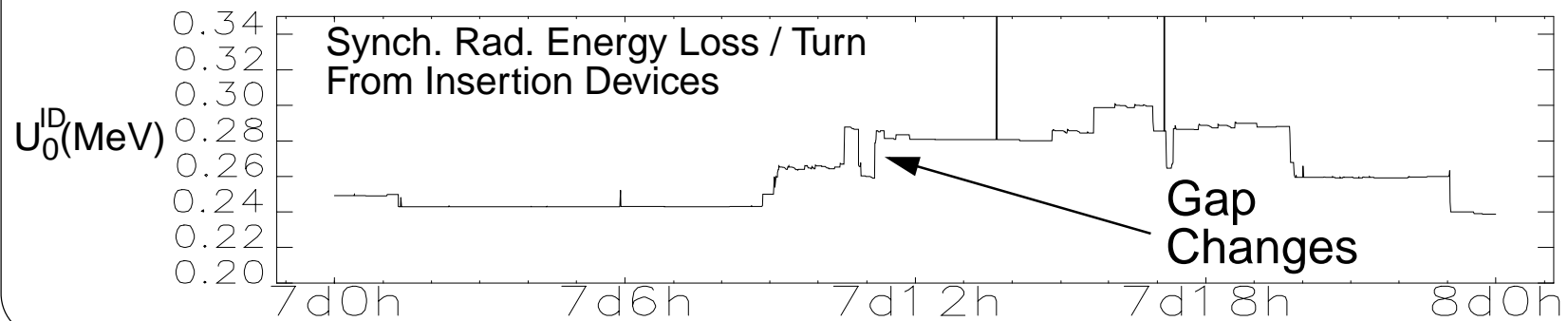
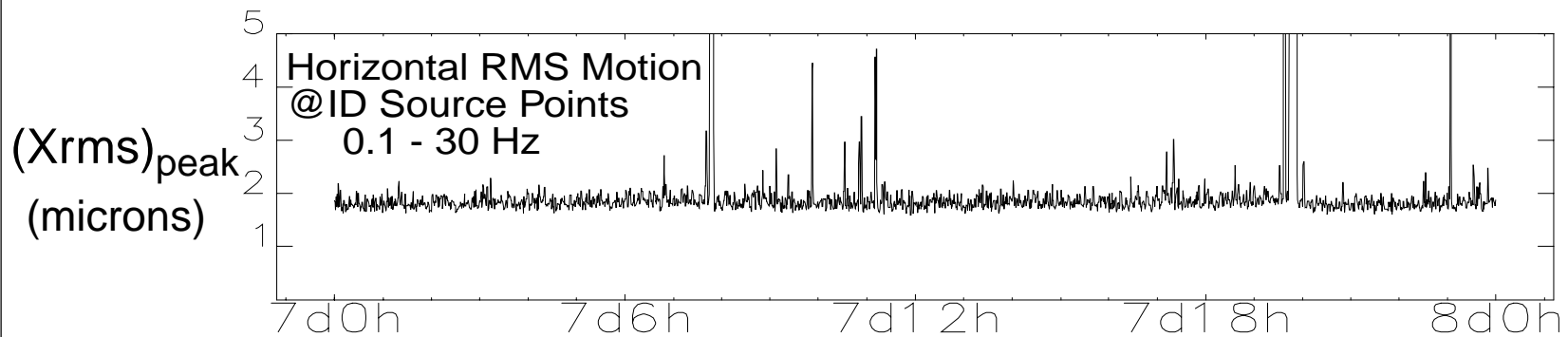
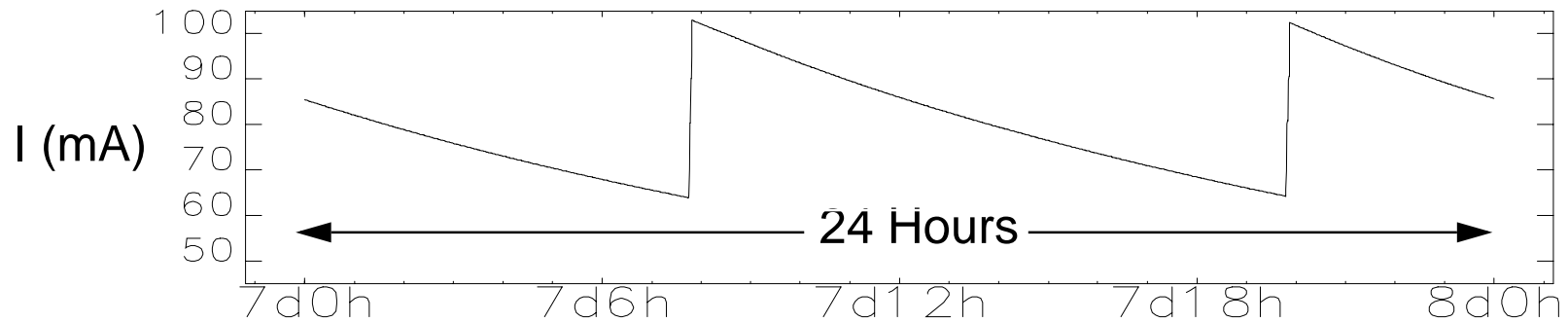




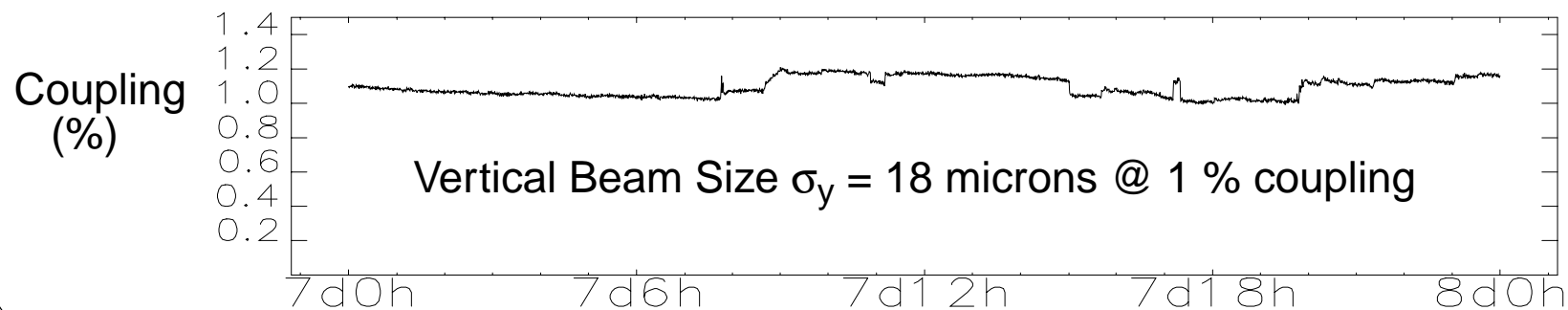
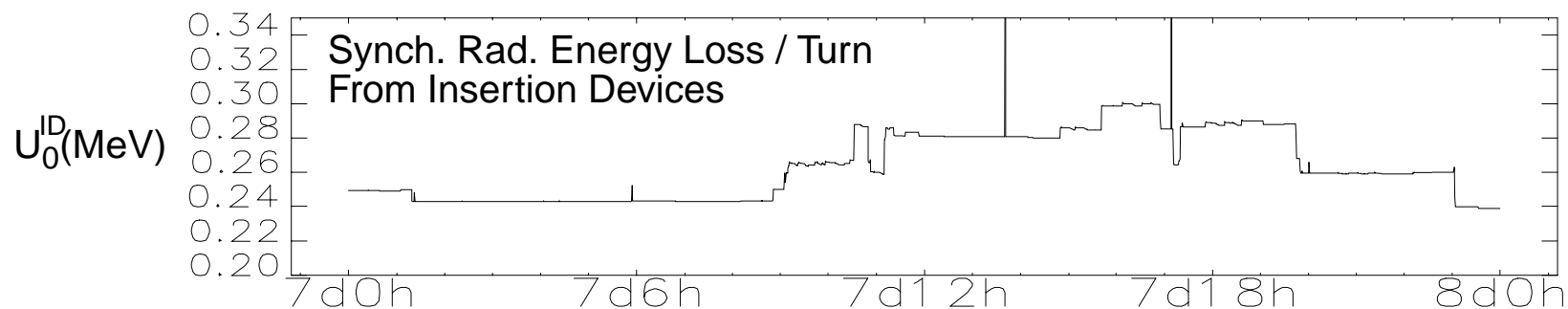
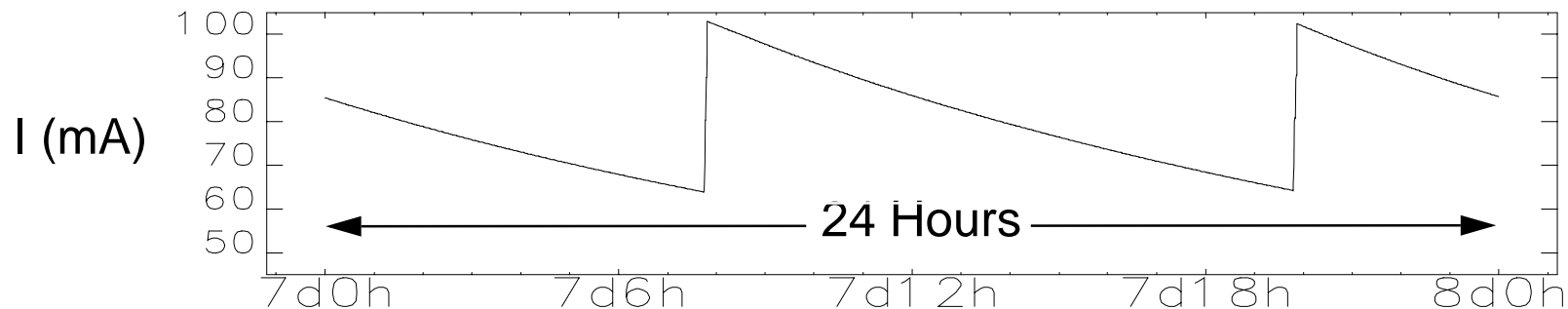
Stored Beam Current



Stored Beam Current

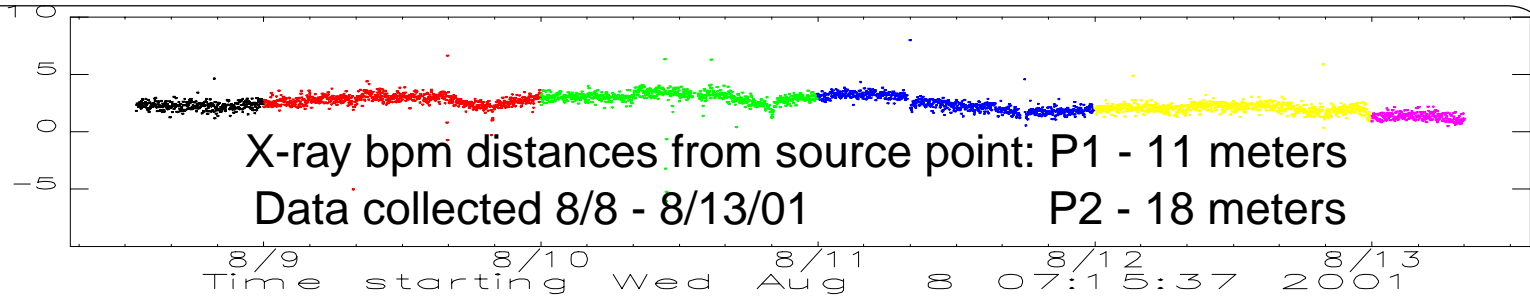


Stored Beam Current

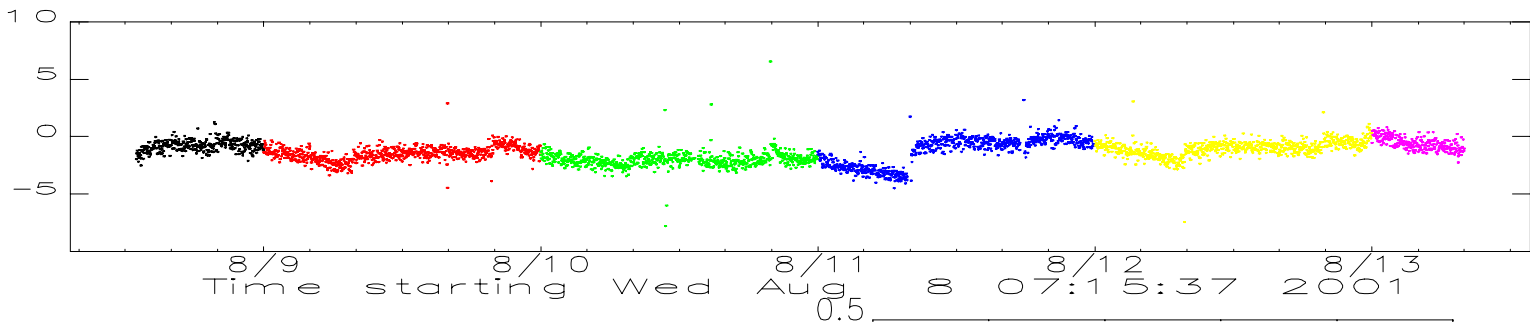


Plots showing < 200 nanoradian rms vertical beam stability over a 5 day period
Colors indicate data for individual days

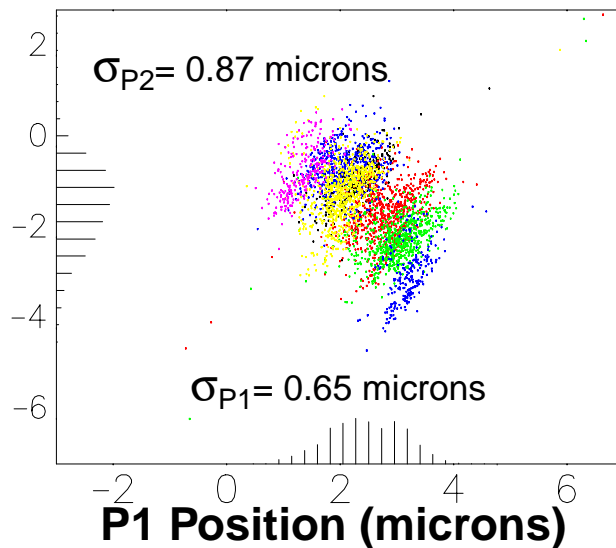
**P1 Position
(microns)**



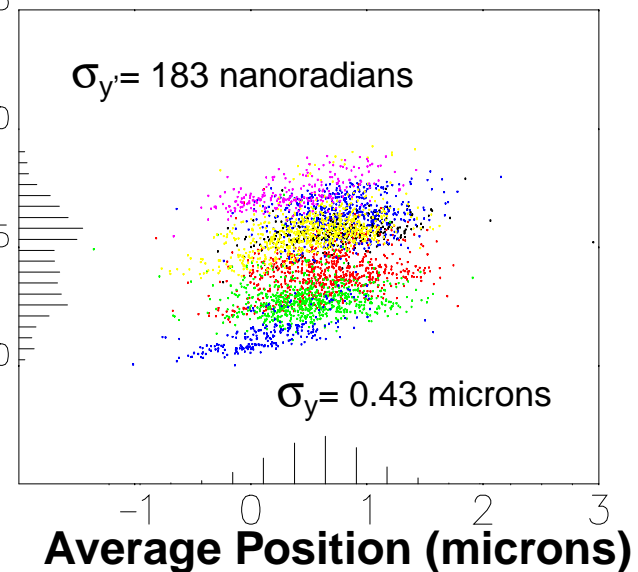
**P2 Position
(microns)**



**P2 Position
(microns)**



**Angle
(microradians)**



Recently Completed Upgrades

- **Replaced monopulse bpm trigger circuitry**
 - Removed constraint on bunch pattern
 - Allows “cogging” option to reduce top-up injection effects
- **Replaced X-ray bpm data acquisition (86 channels)**
 - Allowed factor of ten reduction in long term vertical drift
- **Fabricated mobile X-ray bpm translation stage controllers**
 - Allows for convenient and precise calibration of x-bpms

Upgrade Strategy

- **Things we do well:**

- Real time feedback using monopulse bpms (0.1 - 30 hz with 1.5 kHz data rate)
- Reconfiguring DC orbit control for arbitrary bpms, correctors, and number of singular values (in general the software is excellent and crucial)
- Local steering on demand (software critical here as well)
- Vertical DC global orbit control using bending magnet x-bpms

File
Help

Horizontal \ Vertical \ rf/BP5 \ Horizontal FB \ Vertical FB \

Read configuration from /home/helios/oagData/sr/orbitControllaw/lattices/default/h.default/config

Monitors \ Correctors \

	1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	1	A
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+All
-All
count

Config... \ Read... \ Write... \ Generate controllaw files... \ Generate compensation files... \

Read configuration

Config: P + - h.default

Description: "Removed some nonfunctioning BPMs"

Read(replace) Read(or) Read(and) Read(not) Refresh good/bad

- **Things we know how to do and will do in FY02:**

- Increase update rate of “dc” correction algorithm from 0.4 Hz to 50 Hz or more
 - Involves addition of “data pool” IOC hooked into reflective memory network
- Implement feedforward to reduce ID gap change - induced orbit transients
- Integrate insertion device x-bpms into global and local orbit control algorithms
 - Comprehensive understanding of systematic effects after two years’ intensive study are well in hand

- **Things we're actively working on understanding:**

- Incorporation of x-bpms and narrow-band bpms into fast feedback algorithm (This places a fundamental limit on coupling / brightness)
- Regulation of coupling
- Blade geometry optimization of ID x-bpms, particularly for canted undulators
- Cost / benefit analysis of envisioned upgrade paths for monopulse rfbpm data acquisition
- Use of real-time feedback system to suppress rf system high voltage power supply - induced phase noise

- **Important things not elaborated upon in this presentation:**

- **User sophistication:**

- Several users have developed their own bpm designs. Collaborations being pursued - coordinated studies with SRI-CAT will continue
- User technical working group (twg) meetings, weekly CAT chats, daily control room meetings used as venues for machine physics / user interaction
- Quality and frequency of user interactions is increasing

- **Sector 35 beamline diagnostics:**

- Provides unique opportunity to evaluate beam properties as seen from user's perspective

- Turn-by-turn diagnostics (monopulse bpm's, streak camera etc.) will enable rapid diagnosis and suppression of beam instabilities to support higher current operation.

SECTOR 35: APS DIAGNOSTICS BEAMLINES

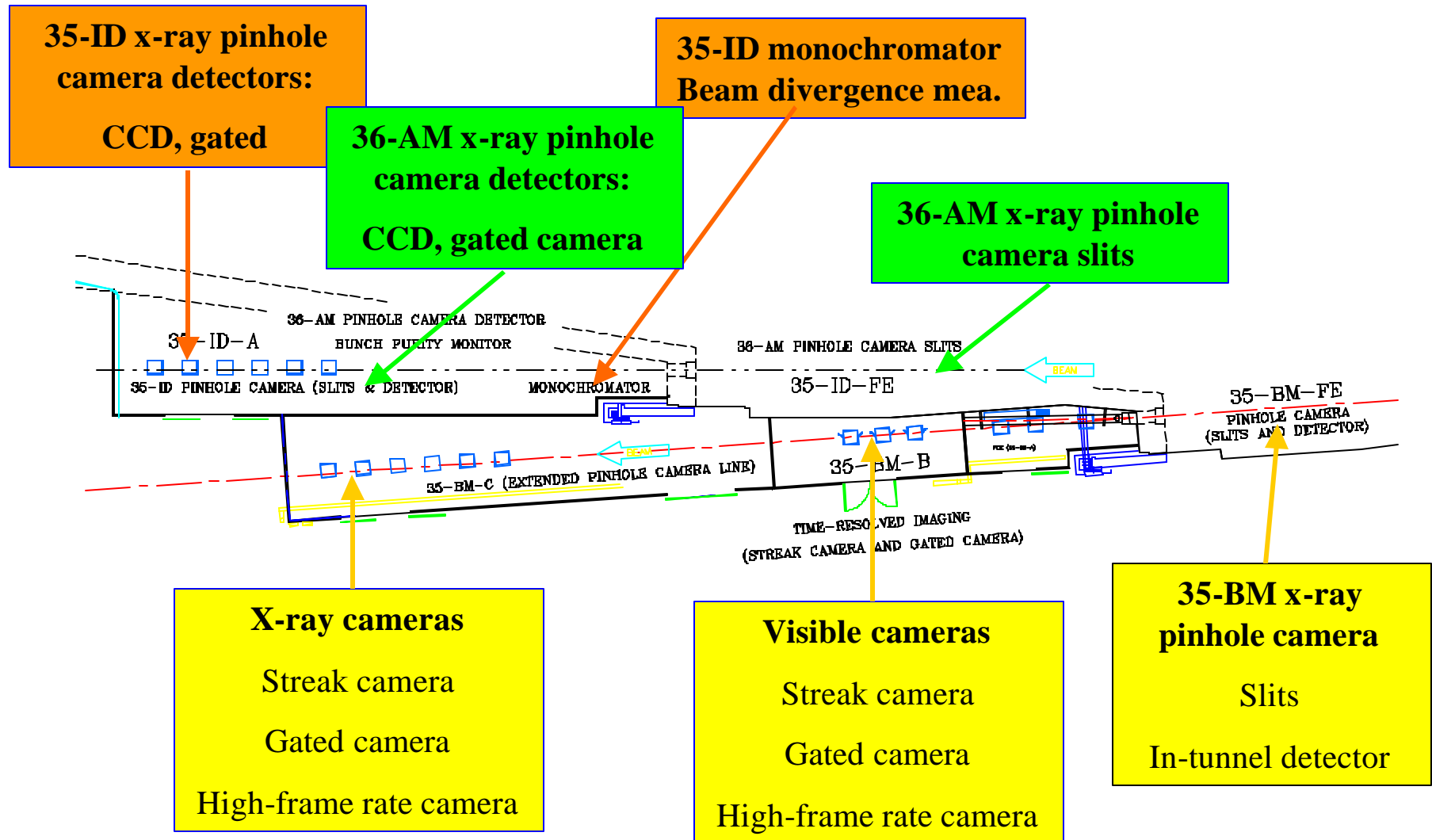
[MISSIONS]

- (1) To support user operations by providing on-line information about the electron beam on a 24-hour basis
- (2) To support machine physics studies by providing photon diagnostics on transverse and longitudinal beam properties
- (3) To conduct research and development of diagnostics for future light sources

[STRATEGIES]

Utilize and develop time-resolved imaging with visible and x-ray synchrotron radiation to support the missions

FLOOR PLAN OF SECTOR 35



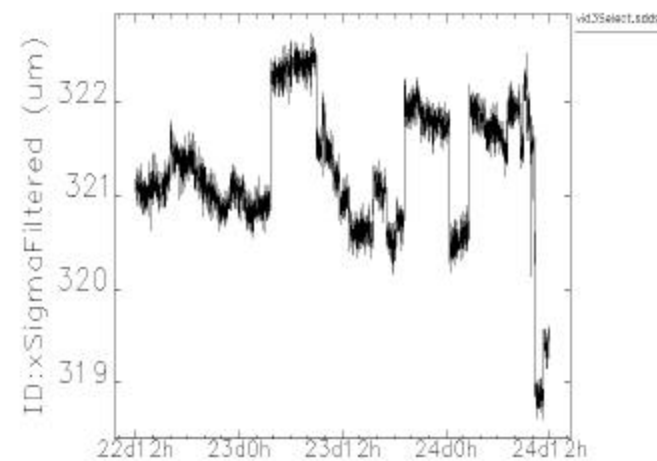
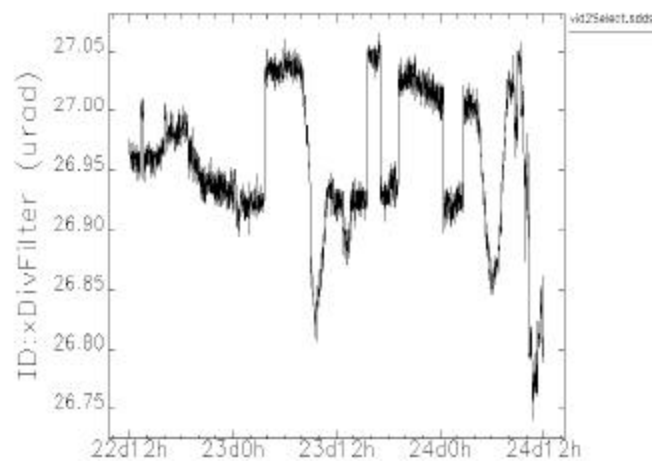
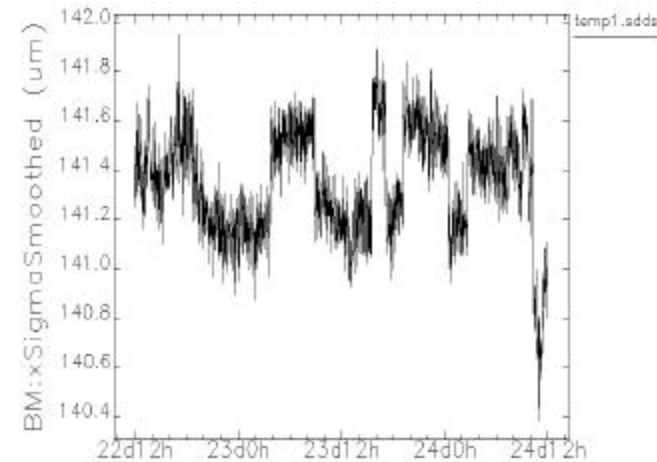
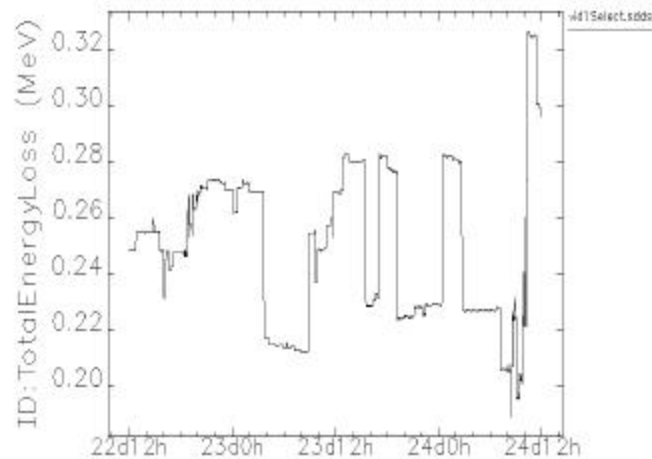
Research Highlights of APS Diagnostics Beamlines (Sector 35)

Measurement	Time scale	Derived beam property	Instruments	Sample Data
Transverse source profile S_x, S_y	30 ms - 1 s	Transverse emittance Energy Spread	X ray pinhole camera	<ul style="list-style-type: none"> Resolution, S/N improvements Horizontal beam emittance vs. ID power loss Subtle instabilities at high current
	3 μ s - 10 ms	Dynamic properties	Gated intensified camera	<ul style="list-style-type: none"> Injection transient (3) motion (damping) Beam instabilities
	2.7ns - 100ms	Dynamic properties	Visible streak camera	<ul style="list-style-type: none"> Beam transients Bunch-train instabilities (4) (instability @ 200 mA)
	0.25 - 100 ms		X ray streak camera	<ul style="list-style-type: none"> X-ray streak transverse profile
	0.25 - 10 ms	Beam motion and dynamic properties	High-frame rate camera	<ul style="list-style-type: none"> > 1 KHz beam motion (user run)
Transverse angular profile S_x, S_y	30 ms - 1 s	Transverse emittance, ID source divergence	35-ID monochromatic beam profile camera	<ul style="list-style-type: none"> User beam coupling vs. ID power loss (1) Low emittance operations data log (2) Beam cross sections
Longitudinal profile S_t	0.6 ps res.	Bunch length	Visible streak camera	<ul style="list-style-type: none"> Bunch length; Head-and-tail instability
	2 ps res.		X ray streak camera	<ul style="list-style-type: none"> X-ray streak synchroscan
Energy spread		Energy Spread Momentum compaction	Diagnostic undulator spectral scan	<ul style="list-style-type: none"> Beam energy spread Momentum compaction
Bunch purity	1 - 10 min		APD detector	<ul style="list-style-type: none"> User run bunch purity QA, Bunch cleaning

SUPPORT OF USER OPERATION: Tracking beam quality

(Standard 7 nm·rad top-up mode operation)

Source size and divergence changes $\sim 1\%$ as a result of user ID gap changes



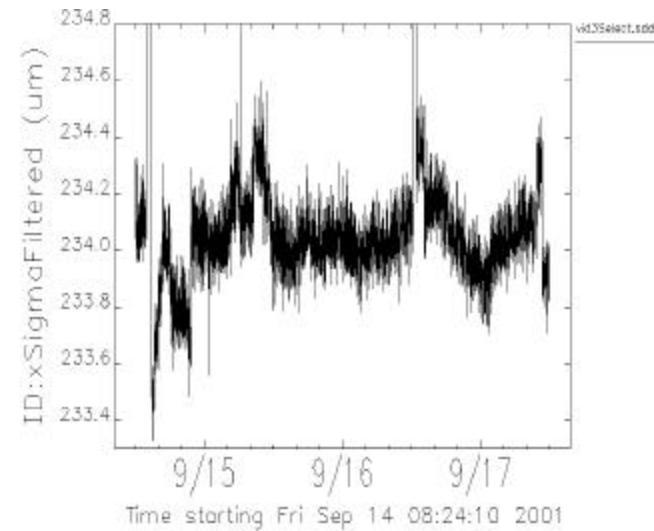
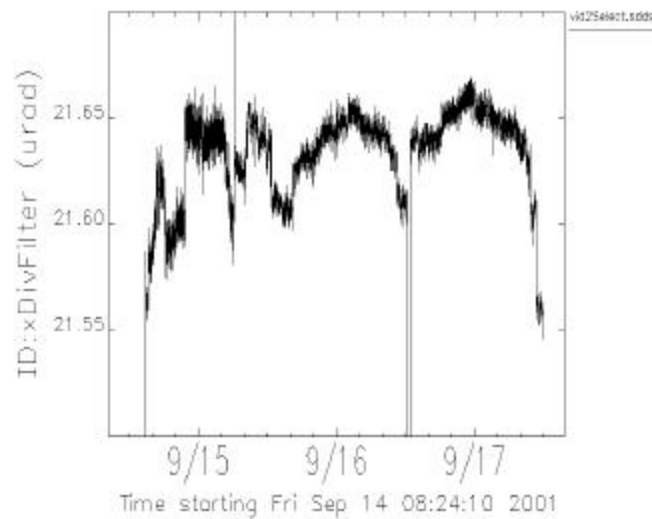
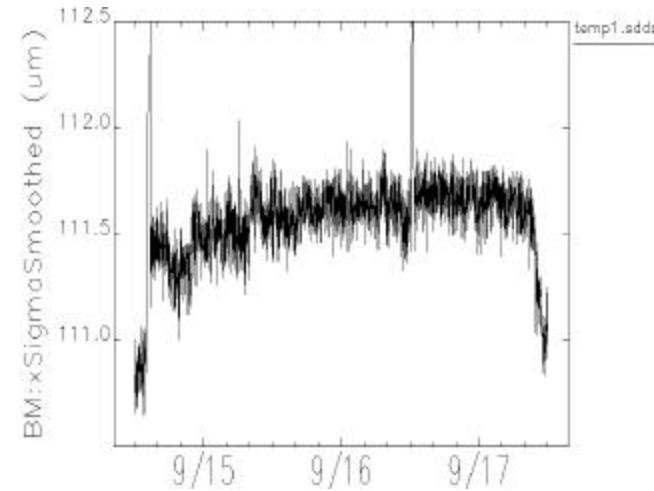
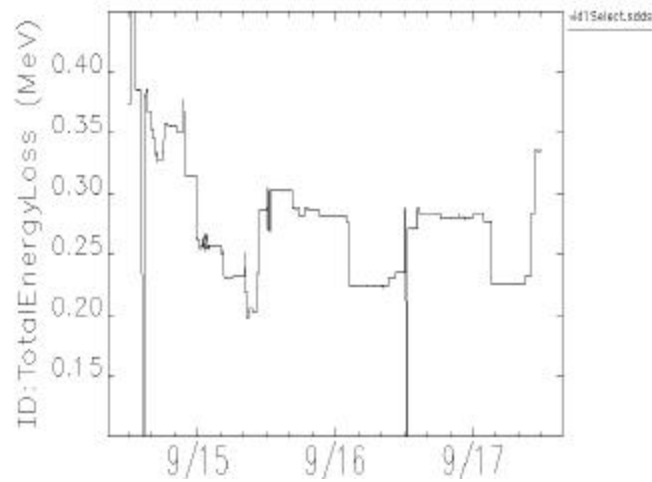
Time starting Sat Sep 22 09:36:04 2001

Time starting Sat Sep 22 09:36:04 2001

SUPPORT OF USER OPERATION: Tracking beam quality

(Low emittance 3 nm·rad top-up mode operation)

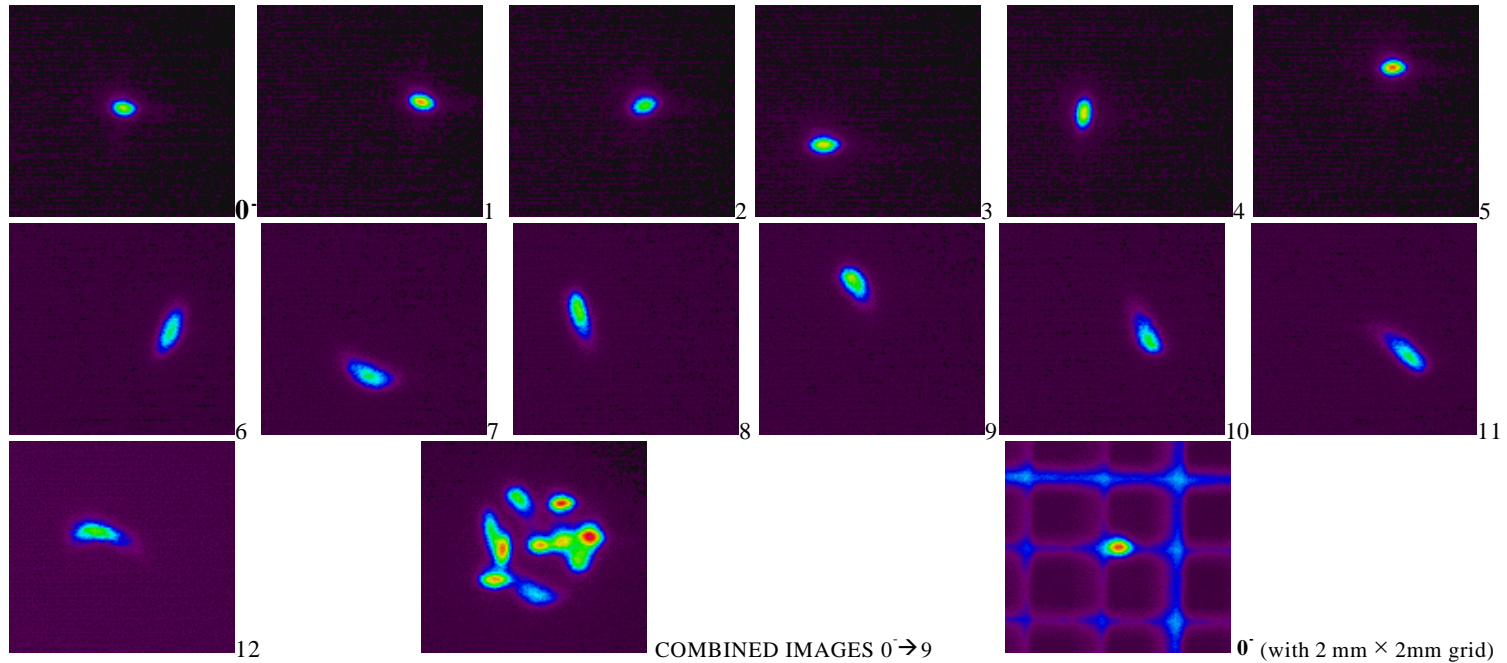
Source size and divergence have contributions from beam energy spread



SUPPORT OF STORAGE RING STUDIES

Injection Transient

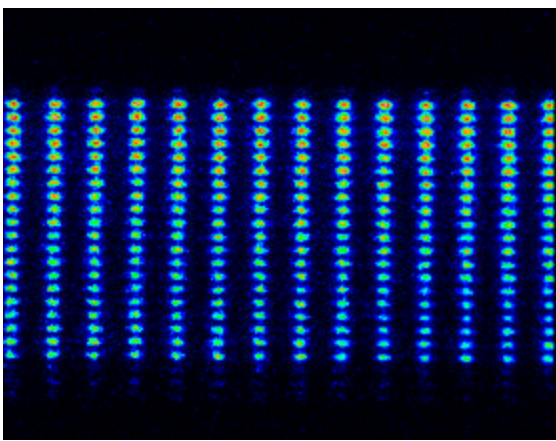
Gated camera single turn images (1/19/98)



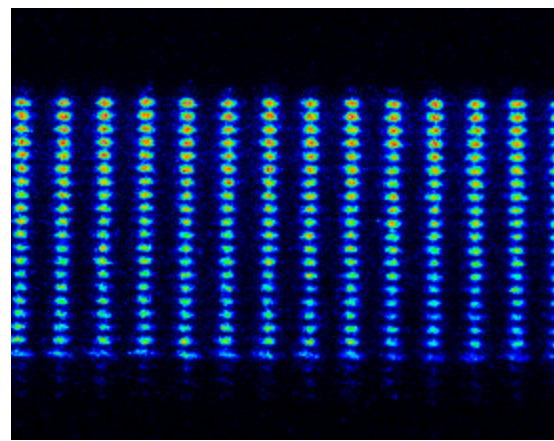
The intensified gated camera captured the transient motion of the stored beam after injection.

- (1) Help understanding of the injection / damping process.
- (2) Multi-turn integrated image provides a quick, visual diagnosis for reduction of vertical coupling.

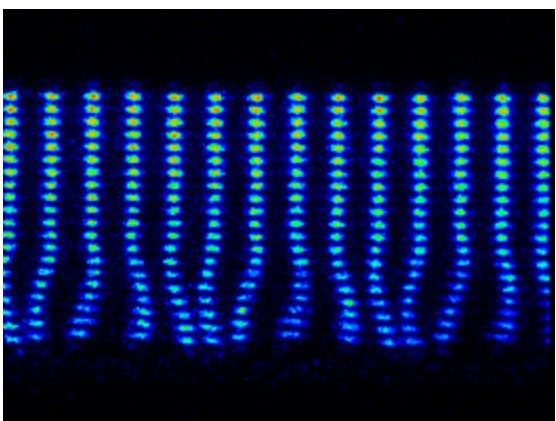
SUPPORT OF STORAGE RING STUDIES: Streak Camera Image of Bunch Train Instability



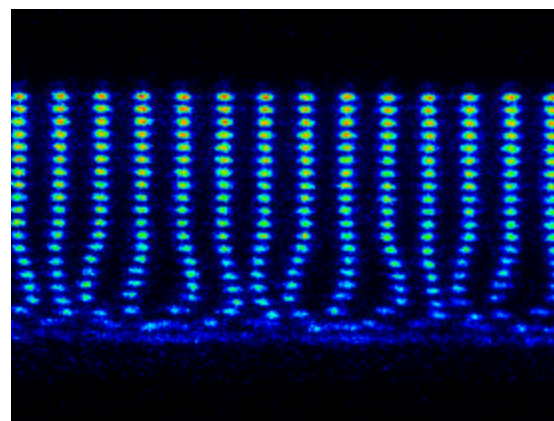
(A) $\xi_x = \xi_0$



(B) $\xi_x = \xi_0 - 3.0$



(C) $\xi_x = \xi_0 - 4.8$



(D) $\xi_x = \xi_0 - 5.2$

CURRENT PROJECTS: FY 2001 AND 2002

- (1) **Cryogenically cooled monochromator:** Measuring beam divergence with high-angular resolution (1.7 urad); measuring high-speed beam motion with high flux available to an undulator. *Status: being assembled*
- (2) **Remote controlled streak camera:** Supporting user operations by logging bunch length daily from MCR. *Status: Being assembled*
- (3) **High Frame rate (32 k/sec) CMOS camera:** Characterization of kHz beam motion during user runs. *Status: design in progress, parts are being procured*
- (4) **Real-time display of beam divergence and source size:** Supporting user operations by providing direct ID measurements. *Status: Being designed*

LONG TERM DEVELOPMENT

- (1) **X-ray imaging of the ID source:** To measure source size ($s_y \sim 17 \text{ } \mu\text{m}$) with adequate resolution and overcome current resolution limit of $40 \text{ } \mu\text{m}$
- (2) **Integration of the photon diagnostics into the storage ring control:** As the storage ring brilliance increases (high-current, small beam size, short bunch), and more flexible bunch pattern for user experiments are implemented, many instabilities will appear.* The diagnostics at Sector 35 will be used to characterize the instabilities, and eventually integrated into feedback systems to stabilize beam operation.
- (3) **Develop time-resolved imaging techniques with the resolution of x-ray optics:** Sector 35 is to be used to develop state of art imaging techniques for accelerator diagnostics. They will not only support the operations and upgrades of the APS facilities, but also perform research and development for the next generation light sources.**

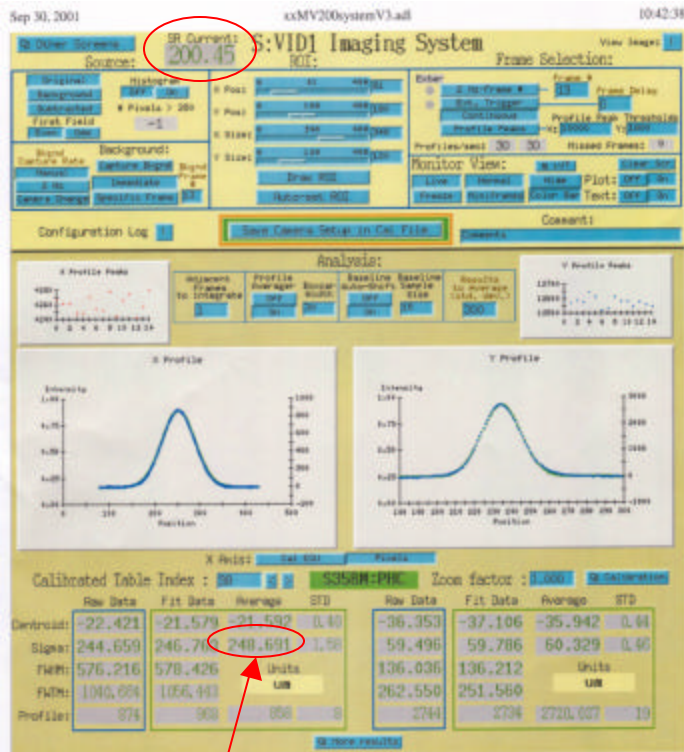
* Example: 200 mA coupled bunch instability

** Example: x-ray streak camera, ID energy spread / momentum compaction measurements

INSTABILITY AT HIGH OPERATING CURRENT

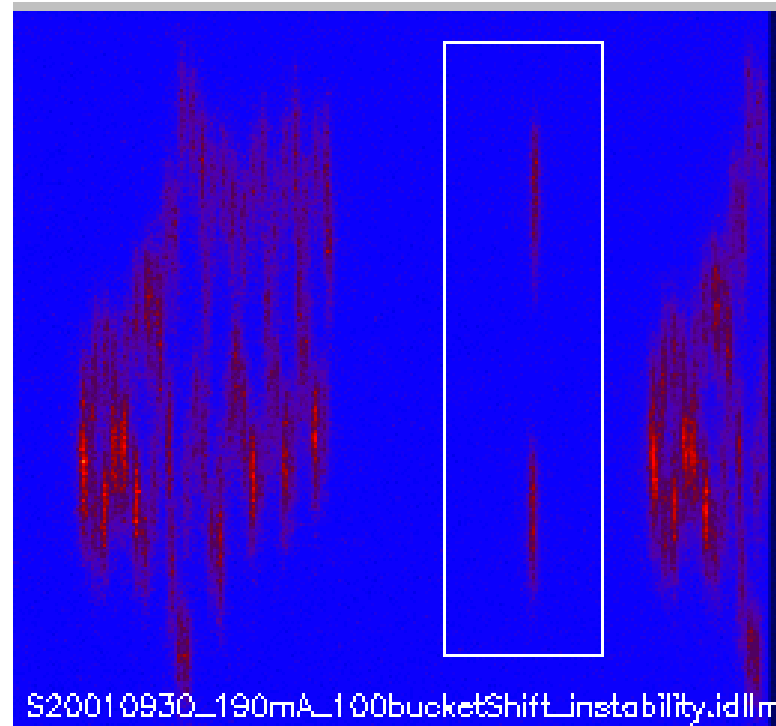
Example: Longitudinal instability observed at **200 mA** test run (9/30/2001)

(A) BM pinhole camera shows a large horizontal beam size at **200 mA** (normal size 141 *mm*)



249 *mm*!

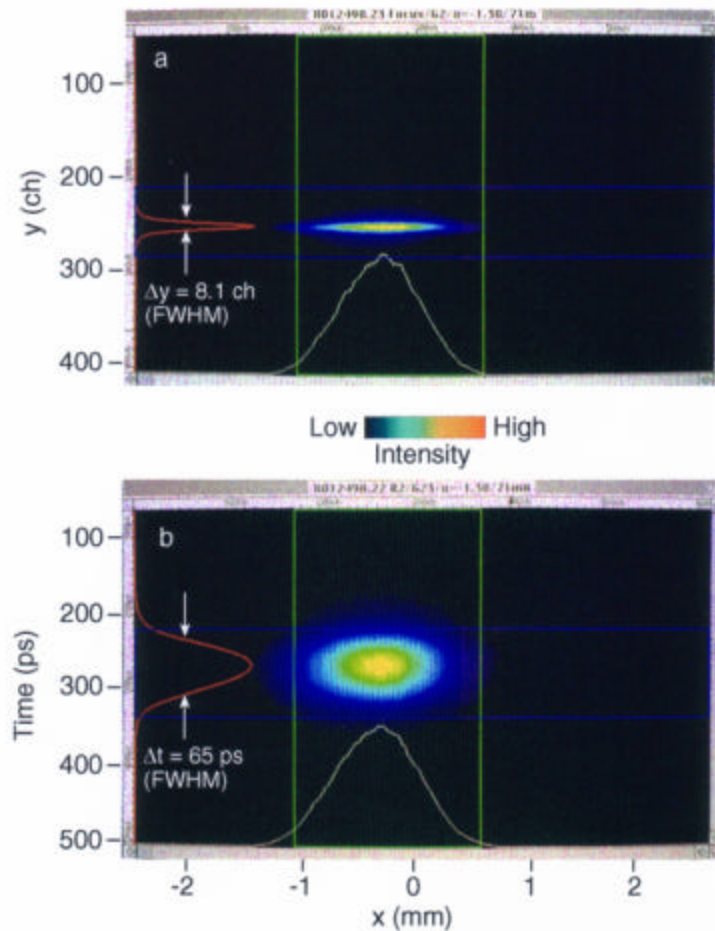
(B) Streak camera image reveals a longitudinal instability.



(This instability was suppressed by changing cavity temperature by 1 degree)

TIME-RESOLVED X-RAY IMAGING (EXAMPLE)

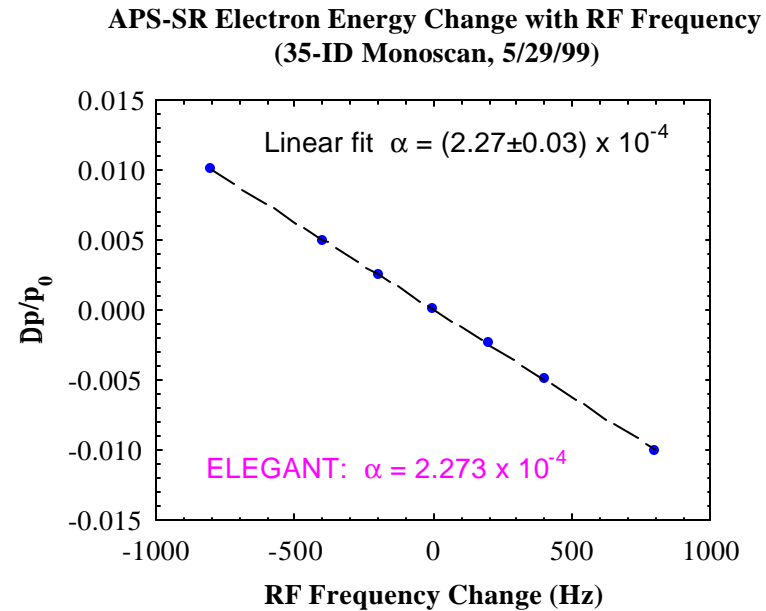
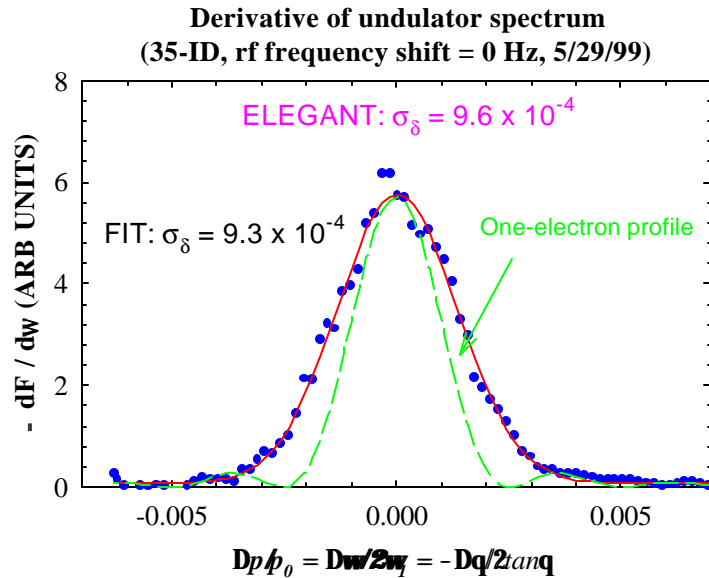
X-Ray Streak Camera Data
(Focus and Synchroscan Modes)



X Ray streak camera couples picoseconds time resolution with few-micron spatial resolution. It is a powerful tool to study beam dynamics for the high brilliant beams the new light sources use.

DEVELOPING NEW DIAGNOSTIC TECHNIQUE

Example: high-sensitivity momentum compaction measurements



$$\alpha = -\frac{\Delta f}{f_0} \bigg/ \frac{\Delta p}{p_0} = -2 \frac{\Delta f}{f_0} \bigg/ \frac{\Delta \omega}{\omega_1} = \frac{2 \tan \theta_0}{f_0} \frac{\Delta f}{\Delta \theta}$$

Advantages of using the undulator angle-integrated spectrum

- **Clean:** independent of beam emittance and lattice functions.
- **Accurate:** only monochromator angle needs good calibration.
- **Simple** data collection and treatment.
- **Efficient:** do not lose photons in apertures, good S/N ratio.

CHARACTERIZE THE STORAGE RING BEAM

Transverse Damping

Gated camera single turn images (1/19/98)

